Army Research Laboratory

An Analysis of Magnesium Alloy AZ31B-H24 for Ballistic Appications

by Tyrone L. Jones, Matthew S. Burkins, and William A. Gooch

ARL-TR-4327 **December 2007**

NOTICES

Disclaimers

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5066

ARL-TR-4327 **December 2007**

An Analysis of Magnesium Alloy AZ31B-H24 for Ballistic Appications

Tyrone L. Jones, Matthew S. Burkins, and William A. Gooch
Weapons and Materials Research Directorate, ARL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
December 2007	Final	March through October 2007

4. TITLE AND SUBTITLE
An Analysis of Magnesium Alloy AZ31B-H24 for Ballistic Appications

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Tyrone L. Jones, Matthew S. Burkins, and William A. Gooch (all of ARL)

5d. PROJECT NUMBER
1L162618AH80

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Weapons and Materials Research Directorate
Aberdeen Proving Ground, MD 21005-5067

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-4327

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. Army Research Laboratory is developing a ballistic specification for the use of magnesium alloy AZ31B-H24 as armor on Army platforms. Data were generated for a range of thicknesses of this magnesium alloy, 0.25 to 4 inches, with the use of five different projectiles. The magnesium performance is parametrically quantified on an equivalent areal density to meet the aluminum alloy 5083-H131, which means a mature, well defined, low-density metal. The results show that the performance of magnesium depends on the diameter of the threat. This research sets a baseline ballistic performance for magnesium alloy AZ31B-H24 for quality control purposes and for use in the development and evaluation of improved alloys.

15. SUBJECT TERMS
aluminum; armor; AZ31B; ballistic performance; magnesium; 5083

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Tyrone L. Jones
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR	20	**19b. TELEPHONE NUMBER** (*Include area code*) 410-278-6223

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

1. Introduction

The U.S. Army Research Laboratory (ARL) has continued to expand the magnesium database for the purpose of creating a military specification for magnesium alloy AZ31B-H24. The favorable mechanical properties of this commercially available alloy have been documented in earlier work (*1*). The purpose of this document is to parametrically compare the ballistic effectiveness, on a weight basis, of the moderate strength, excellent damper AZ31B-H24 to the moderate strength, excellent ductility aluminum alloy 5083-H131. Data for 5083-H131 were obtained from military specification MIL-DTL-46027J(MR) (*2*).

2. Projectiles

2.1 Armor-Piercing (AP) Projectiles

The two projectiles of interest are the U.S. .30-cal M2 AP and the U.S. .50-cal M2 AP, as documented in MIL-DTL-46027J(MR). The U.S. .30-cal projectile contains a hardened steel core that has a hardness of Rockwell C60-65 (*3*). The core has a lead filler encased in a full metal jacket, as shown in figure 1; the lead filler is in front and back of this core. The U.S. .50-cal M2 AP, also shown in figure 1, is similar to the .30-cal M2 AP with size and weight differences and lead filler only in front of this core. The projectile contains a hardened steel core that has a hardness of Rockwell C60-65. The projectile dimensions and masses are listed in table 1.

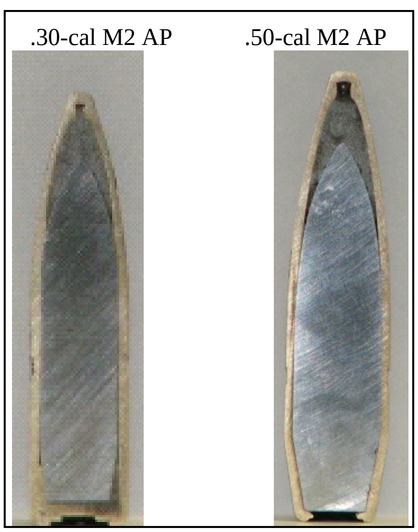


Figure 1. M2 AP projectiles.

Table 1. M2 AP projectile dimensions and masses.

	.30-cal M2 AP (*4*)	.50-cal M2 AP
Length (mm)	35.6	57.9
Diameter (mm)	7.84	12.9
Projectile (g)	10.6	40.1
Core (g)	5.2	25.9
Nose (g)	1.3	3.6
Jacket (g)	4.2	16.3

2.2 Fragment-Simulating Projectiles (FSPs)

FSPs manufactured to meet the specifications of MIL-DTL-46593B (MR) (*5*) are used for the ballistic evaluation of 5083-H131 to meet the MIL-DTL-46027J(MR) specification. These projectiles are steel, right circular cylinders with a chiseled nose at the front end. The other end features an obturator flange. The .22-cal, .50-cal, and 20-mm FSPs were used to evaluate AZ31B-H24. Figure 2 details the shape and dimensions of each FSP.

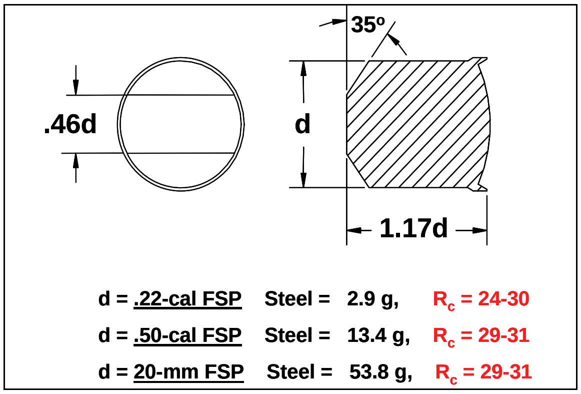


Figure 2. Normalized FSPs (*3*).

3. Magnesium Armor Solutions

The general mechanical properties of AZ31B-H24 magnesium, 5083-H131 aluminum, and rolled homogeneous armor (RHA) steel are provided for comparison in table 2. The tensile and Brinell hardness[1] properties for different tempers of AZ31B are provided in tables 3 and 4. A softer temper, AZ31B-O and a high strength experimental alloy, E675 were evaluated to assess the effect of strength on ballistic performance against some projectiles. The V_{50}[2] protection ballistic limit

[1]Brinell hardness is the load used to force a hardened sphere into a metal surface divided by the area of the indentation created in the surface.

[2]V_{50} is the velocity at which there is an equal probability of a partial or a complete perforation for the given armor and threat.

velocity of the metal plates was statistically determined following the standards of MIL-STD-662F (*6*). The magnesium data will be used to generate a military armor specification for AZ31B-H24.

Figures 3 through 7 provide the ballistic V_{50} limit velocity data for the plates as a function of areal density (weight per unit area; thickness times density) for the various projectiles.

Table 2. General mechanical properties (*3*).

Property	**AZ31B**	**RHA**	**AL5083**
Density (g/cm^3)	1.77	7.86	2.66
Ultimate Tensile Strength (MPa)	270	1170	350
Young's Modulus (GPa)	44	205	70
Specific Strength (MPa•cm^3/g)	153	150	130
Specific Modulus (GPa•cm^3/g)	24.9	26.1	26.3

Table 3. AZ31B tensile properties (*3*).

Relative Strength	**Magnesium Alloy-Temper**	**Ultimate Tensile Strength**		**Tensile Yield Strength**		**ETF**	**Relative Ductility**
		ksi	**MPa**	**ksi**	**MPa**	**percent**	
↑	AZ31B-H24	39	269	27	186	9	↓
	ZK10-F	37	255	27	186	10	
	AZ31B-O	36	248	21	145	12	
	AZ31B-O "Super Annealed"	35	241	19	131	14	

ETF = elongation to failure; ksi = kilopounds per square inch; MPa = megapascals
"Super annealed" AZ31B-O was created by precipitation hardening at 700 °F for 2 hours. We then cooled it to room temperature by decreasing the oven set point by 50 °F per hour.

Table 4. Brinell hardness properties.

Magnesium Alloy-Temper	**Hardness[a] (HBN)**
AZ31B-H24	61.0
AZ31B-F	59.0
AZ31B-O	54.0
AZ31B-O super annealed	33.6

[a]Tested on 500-kg Brinell scale

The limit velocities shown are acceptance velocities from MIL-DTL-46027J and actual test V_{50} for AZ31B. The AP ballistic performance data show AZ31B to be very similar in mass efficiency against these projectiles. The increased thickness of the monolithic AZ31B did not improve the overall ballistic performance. The FSP ballistic performance data show that at thinner gauge monolithic plate, the AZ31B outperforms 5083AL. The thickness of the plate is more of a factor than the strength at the lower areal densities. There is a cross-over, which depends on the threat diameter, where the strength surpasses the thickness and becomes the dominant factor in the overall ballistic performance. It is also clear that strength is more of a factor against the flat-headed high-energy FSPs than AP projectiles. In addition, the excellent ductility of 5083AL relocates some of the kinetic energy of the FSP into plastic deformation. Experimental observation

revealed that more ductility in AZ31B could improve the back face spalling and thus the ballistic performance of the plate. Hardness was not a factor for AZ31B against the AP core and FSP cylinder since the projectiles remained fully intact after impact. Hardness was not a factor for 5083AL against the AP core that remained fully intact. However, hardness was a small factor for 5083AL against the FSP cylinder since the projectile slightly mushroomed after impact.

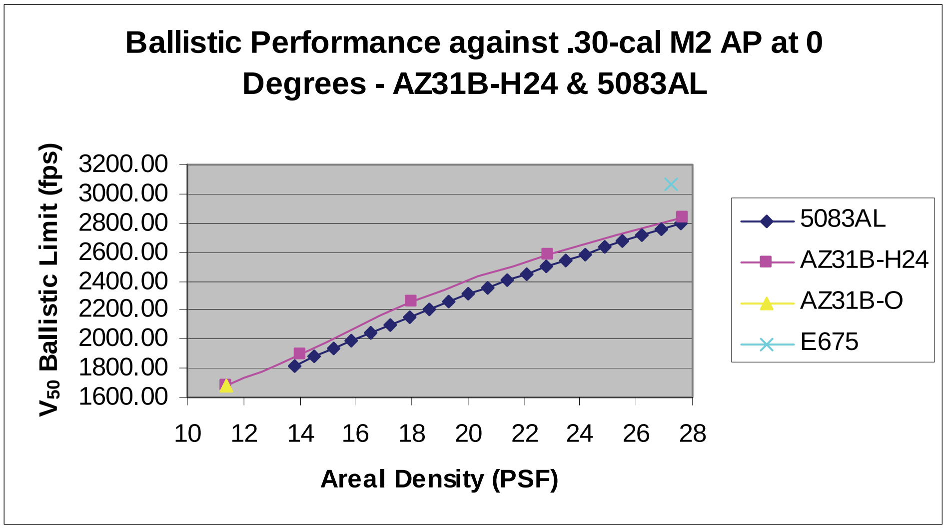


Figure 3. Estimated V_{50} ballistic limit of the .30-caliber M2 AP.

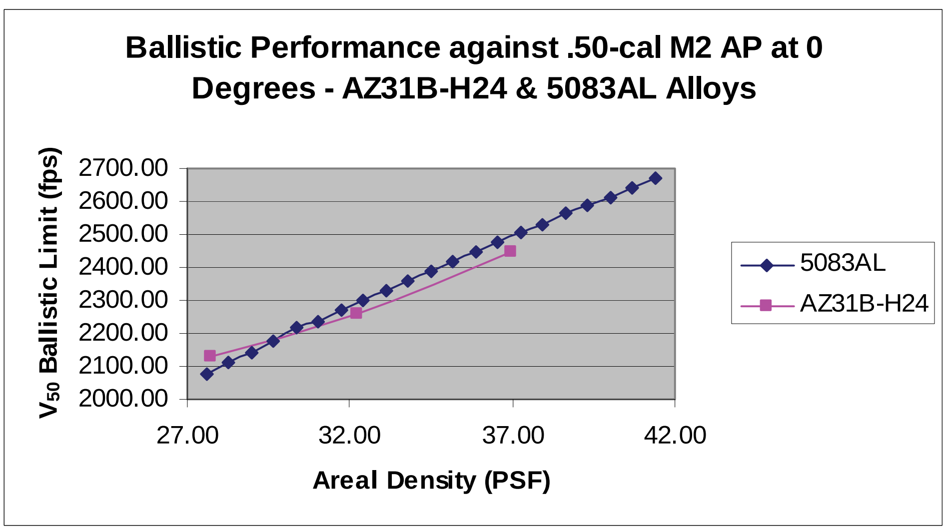
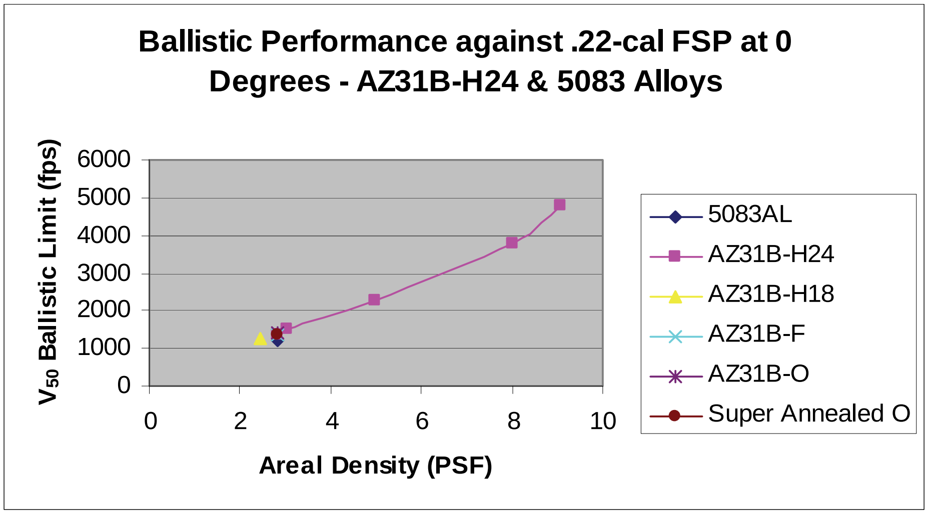


Figure 4. Estimated V_{50} ballistic limit of the .50-caliber M2 AP.



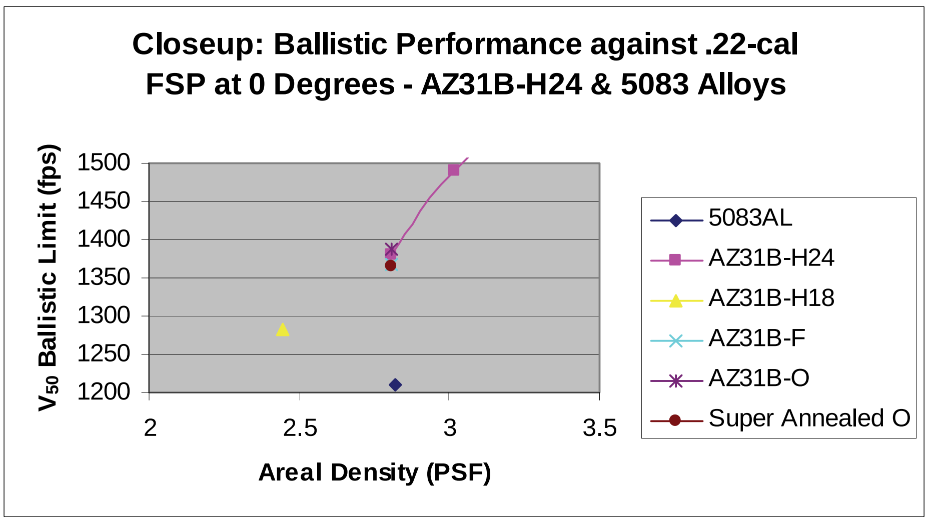


Figure 5. Estimated V_{50} ballistic limit of the .22-caliber FSP.

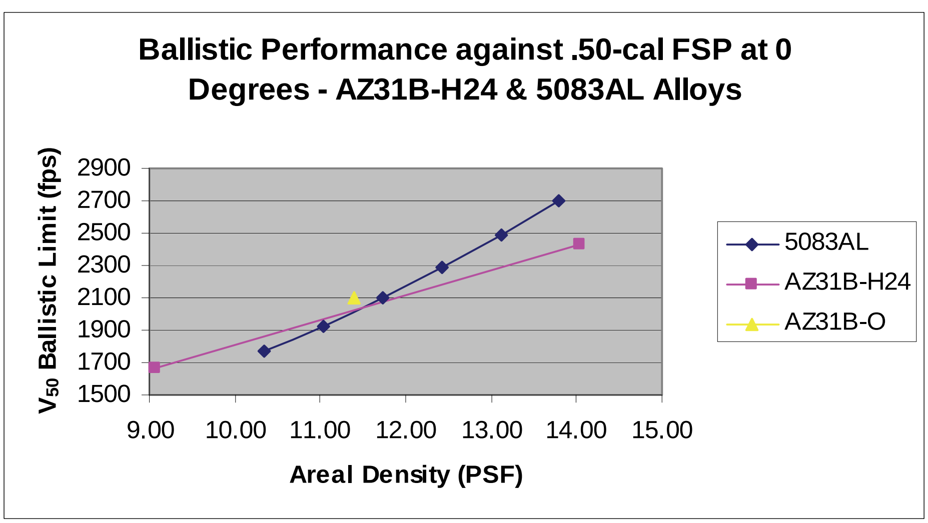


Figure 6. Estimated V_{50} ballistic limit of the .50-caliber FSP.

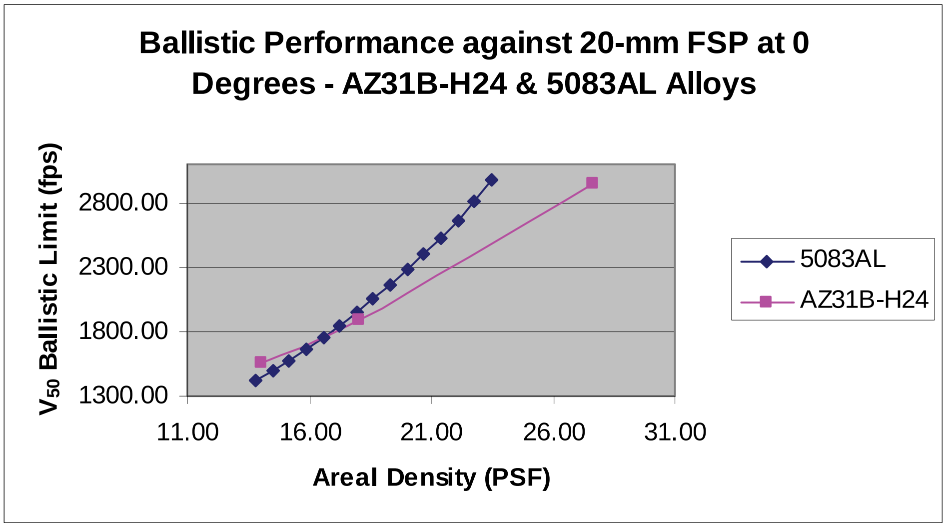


Figure 7. Estimated V_{50} ballistic limit of the 20-mm FSP.

4. Conclusions

AZ31B-H24 is competitive to 5083-H131 aluminum armor on an equivalent weight basis. This magnesium has a better ballistic performance than 5083-H131 against the AP projectiles while 5083-H131 offers better fragment protection. The spall strength of AZ31B might be improved with alloying. The cost of AZ31B-H24 is currently \$7 to \$8 per pound versus for \$2.50 to \$3 per pound for 5083-H131. ARL is currently working on the generation of a military armor specifica-tion that will allow armor system manufacturers to qualify their magnesium material for use in combat vehicles.

5. References

1. Jones, T. L.; DeLorme, R. D.; Burkins, M. S.; Gooch, W. A. *Ballistic Evaluation of Magnesium Alloy AZ31B*; ARL-TR-4077, U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, April 2007.

2. U.S. Army Research Laboratory. Armor Plate, Aluminum Alloys. Weldable 5083 and 5456, Military Specification MIL-DTL-46027J (MR), Aberdeen Proving Ground, MD, 04 September 1998.

3. Jones, T. L.; DeLorme, R. D.; Burkins, M. S.; Gooch, W. A. Ballistic Performance of Magnesium Alloys, PowerPoint Presentation. *TMS 2007 Annual Meeting & Exhibition*, Orlando, FL, 25 March 2007.

4. Jones, T. L. *Ballistic Performance of Titanium Alloys Ti-6Al-4V Versus Russian Titanium*; ARL-CR-0533, U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, February 2004.

5. U.S. Army Research Laboratory. *Projectile, Calibers .22, .30, .50, and 20-mm Fragment-Simulating*; Military Specification MIL-DTL-46593B (MR); Aberdeen Proving Ground, MD, 06 July 2006.

6. U.S. Army Research Laboratory. *V_{50} Ballistic Test for Armor*; Military Standard MIL-STD-662F; Aberdeen Proving Ground, MD, 18 December 1997.

NO. OF COPIES	ORGANIZATION
1 (PDF ONLY)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FORT BELVOIR VA 22060-6218
1	US ARMY RSRCH DEV & ENG CMD SYSTEMS OF SYSTEMS INTEGRATION AMSRD SS T 6000 6TH ST STE 100 FORT BELVOIR VA 22060-5608
1	DIRECTOR US ARMY RESEARCH LAB IMNE ALC IMS 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRD ARL CI OK TL 2800 POWDER MILL RD ADELPHI MD 20783-1197
2	DIRECTOR US ARMY RESEARCH LAB AMSRD ARL CS OK T 2800 POWDER MILL RD ADELPHI MD 20783-1197
4	CDR US ARMY TACOM ATTN AMSTA TR S T FURMANIAK L PROKURAT FRANKS D TEMPLETON MS 263 WARREN MI 48397-5000
1	CDR US ARMY TACOM ATTN AMSRD TAR R D HANSEN MS 271 WARREN MI 48397-5000
1	PM ATTN SFAE GCSS HBCTS JROWE MS 325 WARREN MI 48397-5000
2	CDR NGIC ATTN J CRIDER W GSTATTENBAUER 2055 BOULDERS RD CHARLOTTESVILLE VA 22911-8318

NO. OF COPIES	ORGANIZATION
1	CRUSADER OPM ATTN SFAE GCSS CR E B ROOPCHAND BLDG 171A PICATINNY ARSENAL NJ 07806-5000
1	DIRECTOR DARPA 3701 NORTH FAIRFAX DR ARLINGTON VA 22203-1714
1	PM BFVS ATTN SFAE GCSS W BV S M KING WARREN MI 48397-5000
1	CDR CARDEROCK DIV NSWC ATTN CODE 28 R PETERSON 9500 MACARTHUR BLVD W BETHESDA MD 20817-5700
2	LAWRENCE LIVERMORE NATL LAB ATTN R LANDINGHAM L372 J REAUGH L282 PO BOX 808 LIVERMORE CA 94550
2	LOS ALAMOS NATL LAB ATTN F ADDESSIO M BURKETT PO BOX 1663 LOS ALAMOS NM 87545
1	NAVAL RSCH LABORATORY ATTN CODE 6684 4555 OVERLOOK AVE SW WASHINGTON DC 20375
5	SANDIA NATL LAB ATTN J ASAY MS 1811 R BRANNON MS 0751 L CHHABILDAS MS 1811 D CRAWFORD MS 0836, 9116 M FORRESTAL DIV 1551 PO BOX 5800 ALBUQUERQUE NM 87185-0307
1	AIR FORCE ARMAMENT LAB ATTN AFATL DLJW W COOK EGLIN AFB Fl 32542
4	INST FOR ADVNCD TECH ATTN S BLESS H FAIR J HODGE R SUBRAMANIAN 3925 W BRAKER LANE AUSTIN TX 78759-5316

NO. OF COPIES	ORGANIZATION
1	UNIV OF DAYTON RSCH INST ATTN KLA 14 N BRAR 300 COLLEGE PARK DAYTON OH 45469-0182
3	SOUTHWEST RSCH INST ATTN C ANDERSON J RIEGEL J WALKER 6220 CULEBRA RD SAN ANTONIO TX 78238
4	US DEPT OF ENERGY ALBANY RSCH CENTER ATTN J HANSEN (2 CYS) P TURNER (2 CYS) 1450 QUEEN AVE SW ALBANY OR 97321-2198
1	BROWN UNIV DIV OF ENGINEERING ATTN R CLIFTON PROVIDENCE RI 02912
2	UNIV OF CA SAN DIEGO DEPT OF APPL MECH & ENGR SVC RO11 ATTN S NEMAT NASSER M MEYERS LA JOLLA CA 92093-0411
2	AERONAUTICAL RSCH ASSN ATTN R CONTILIANO J WALKER PO BOX 2229 50 WASHINGTON RD PRINCETON NJ 08540
1	ALLIANT TECHSYSTEMS INC ATTN G JOHNSON 5050 LINCOLN DR EDINA MN 55436
1	APPLIED RSCH ASSN INC ATTN D GRADY 4300 SAN MATEO BLVD NE STE A ALBUQUERQUE NM 87110
1	BRIGGS COMPANY ATTN J BACKOFEN 2668 PETERSBOROUGH ST HERNDON VA 222071-2443
3	CERCOM ATTN R PALICKA G NELSON B CHEN 1960 WATSON WAY VISTA CA 92083

NO. OF COPIES	ORGANIZATION
1	CYPRESS INTERNTL ATTN A CAPONECCHI 1201 E ABINGDON DR ALEXANDRIA VA 22314
1	R J EICHELBERGER 409 W CATHERINE ST BEL AIR MD 21014-3613
1	EPSTEIN AND ASSN ATTN K EPSTEIN 2716 WEMBERLY DR BELMONT CA 94002
1	GENERAL RSCH CORP PO BOX 6770 SANTA BARBARA CA 93160-6770
3	GDLS ATTN W BURKE MZ436 21 24 G CAMPBELL MZ436 30 44 D DEBUSSCHER MZ436 20 29 38500 MOUND RD STERLING HTS MI 48310-3200
3	GDLS ATTN J ERIDON MZ436 21 24 W HERMAN MZ435 01 24 S PENTESCU MZ436 21 24 38500 MOUND RD STERLING HTS MI 48310-3200
1	INTERNATL RSCH ASSN ATTN D ORPHAL 4450 BLACK AVE PLEASANTON CA 94566
1	JET PROPULSION LAB IMPACT PHYSICS GROUP ATTN M ADAMS 4800 OAK GROVE DR PASADENA CA 91109-8099
3	OGARA HESS & EISENHARDT ATTN G ALLEN D MALONE T RUSSELL 9113 LE SAINT DR FAIRFIELD OH 45014
2	ALLVAC OREMET FACILITY ATTN J KOSIN B MAHONEY 530 34TH AVE SW PO BOX 460 ALBANY OR 97321

NO. OF COPIES	ORGANIZATION
4	POULTER LABORATORY SRI INTERNATIONAL ATTN D CURRAN R KLOOP L SEAMAN D SHOCKEY 333 RAVENSWOOD AVE MENLO PARK CA 94025
6	RMI TITANIUM CO ATTN J BENNETT E CHRIST F JANOWSKI W PALLANTE S ROBERTSON O YU 1000 WARREN AVE NILES OH 44446
1	TIMET ATTN J FANNING PO BOX 2128 HENDERSON NV 89009
1	TWIST ATTN J BARBER 1999 BROADWAY STE 4300 DENVER CO 80202
1	SIMULA INC ATTN R WOLFFE 10016 SOUTH 51 ST ST PHOENIX AZ 85044
3	UNITED DEFENSE LP ATTN E BRADY R JENKINS K STRTTMATTER PO BOX 15512 YORK PA 17405-1512
1	ZERNOW TECH SVCS INC ATTN L ZERNOW 425 W BONITA AVE STE 208 SAN DIMAS CA 91773
1	PENN STATE UNIV ATTN DAVE SWANSON 504L APPLIED SCIENCE BLDG STATE COLLEGE PA 16802
5	MENA ATTN RICK DeLORME 1001 COLLEGE STREET PO BOX 258 MADISON IL 62060

NO. OF COPIES	ORGANIZATION
1	APPLIED RSCH LAB ACOUSTICS PROGRAM ATTN D SWANSON 504L APPLIED SCI BLDG UNIVERSITY PK PA 16803
1	RITA JONES 80 PALISADE AVE WHITE PLAINS NY 10607
1	CHARLIA CONYERS 2412 HAY RAKE CT HERNDON VA 20171
1	RECHELLE JACKSON 426 WASHINGTON ST ABERDEEN MD 21001
1	TIAX LLC ATTN JACOB PRETORIUS 15 ACORN PARK CAMBRIDGE MA 02140
1	UNIV OF VIRGINIA DEPT OF MATERIALS SCI & ENG SCHOOL OF ENG & APPL SCIENCE ATTN HAYDN WADLEY B214 THORNTON HALL 116 ENGINEERS WAY CHARLOTTESVILLE VA 22903
1	PACIFIC NORTHWEST NAIL LAB ATTN ERIC NYBERG MSIN P7-82 902 BATTELLE BLVD RICHLAND WA 99352
1	CELLULAR MATERIALS INTERNATL INC ATTN YELLAPU MURTY 2 BOARS HEAD LANE CHARLOTTESVILLE VA 22903
1	EMBASSY OF AUSTRALIA COUNSELLOR DEFENCE SCIENCE 1601 MASSACHUSETTS AVE NW WASHINGTON DC 20036-2273
	ABERDEEN PROVING GROUND
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL CI OK (TECH LIB) BLDG 4600

NO. OF COPIES	ORGANIZATION
1	DIR USA EBCC ATTN SCBRD RT 5183 BLACKHAWK RD APG EA MD 21010-5424
1	CDR USA SBCCOM ATTN AMSCB CII 5183 BLACKHAWK RD APG EA MD 21010-5424
1	DIR USAMSAA ATTN AMXSY D BLDG 392
1	CDR USATEC ATTN STEAC LI LV E SANDERSON BLDG 400
1	CDR US ARMY DTC ATTN CSTE DTC TT T M SIMON RYAN BLDG
2	DIR USARL ATTN AMSRD ARL SL BM A DIETRICH AMSRD ARL SL BE W BRUCHEY BLDG 328
9	DIR USARL ATTN AMSRD ARL D J MILLER V WEISS AMSRD ARL WM J SMITH J McCAULEY P PLOSTINS T WRIGHT AMSRD ARL WM B M ZOLTOSKI AMSRD ARL WM BD D LOWRY AMSRD ARL WM BF S WILKERSON
13	DIR USARL ATTN AMSRD ARL WM M J BEATTY S McKNIGHT B DOWDING AMSRD ARL WM MB R CARTER L KECSKES S MATHAUDHU D SNOHA AMSRD ARL WM MC W ROY R SQUILLACIOTI AMSRD ARL WM MD E CHIN B CHEESEMAN K CHO J MONTGOMERY
30	DIR USARL ATTN AMSRD ARL WM T B BURNS P BAKER AMSRD ARL WM TA C HOPPEL M BURKINS (5 CYS) W GOOCH (5 CYS) T HAVEL D HACKBARTH E HORWATH T JONES (10 CYS) D KLEPONIS B LEAVY J RUNYEON S SCHOENFELD
13	DIR USARL ATTN AMSRD ARL WM TB R BANTON R GUPTA AMSRD ARL WM TC R COATES R ANDERSON T FARRAND K KIMSEY D SCHEFFLER L MAGNESS R MUDD S SCHRAML S SEGLETES R SUMMERS W WALTERS
13	DIR USARL ATTN AMSRD ARL WM TD S BILYK T BJERKE D CASEM J CLAYTON D DANDEKAR M GREENFIELD Y HUANG B LOVE H MEYER M RAFTENBERG E RAPACKI M SCHEIDLER T WEERASOORIYA
1	DIR USARL ATTN AMSRD ARL WM TE C HUMMER BLDG 1116A

NO. OF COPIES	ORGANIZATION
	FOREIGN ADDRESSES
2	AERONAUTICAL & MARITIME RSCH LAB N MURMAN S C1MPOERU D PAUL PO BOX 4331 MELBOURNE VIC 3001 AUSTRALIA
1	ARMSCOR L DU PLESSIS PRIVATE BAG X337 PRETORIA 0001 SOUTH AFRICA
1	DEFENCE RSCH AGENCY FORT HALSTEAD SEVEN OAKS KENT TN 14 7BP UNITED KINGDOM
1	CARLOS III UNIV OF MADRID C NAVARRO ESCUELA POLTEENICA SUPERIOR C/BUTARQUE 15 28911 LEGANES MADRID SPAIN
1	CELIUS MATERIAL TEKNIK KARLSKOGA AB L HELLNER S 69180 KARLSKOGA SWEDEN
3	CENTRE D'ETUDES GRAMAT J CAGNOUX C GALLIC J TRANCHET GRAMAT 46500 FRANCE
1	MINISTRY OF DEFENCE DGA DSP STTC G BRAULT 4 RUE DE LA PORTE D'ISSY 00460 ARMEES F 75015 PARIS FRANCE
1	CONDAT J KIERMEIR MAMLANSTR 28 8069 SCHEYERN FERNHAG GERMANY

NO. OF COPIES	ORGANIZATION
1	OSAKA UNIVERSITY JOINING & WELDING RSCH INST ATTN DR KATSUYOSHI KONDOH 11-1 MIHOGAOAKA IBARAKI OSAKA 567-0047 JAPAN
2	DEFENCE PROCUREMENT AGCY G LAUBE W ODERMATT BALLISTICS WPNS & COMBAT VEHICLE TEST CTR CH 3602 THUN SWITZERLAND
1	TDW M HELD POSTFACH 1340 D 86523 SCHROBENHAUSEN GERMANY
4	DEFENSE RSCH AGENCY W CARSON T HAWKINS B JAMES B SHRUBSALL PORTON DOWN SALISBURY WTTTS SP 04 OJQ UNITED KINGDOM
1	DEFENCE RSCH ESTAB VALCARTIER ARMAMENTS DIV R DELAGRAVE 2459 PIE XI BLVD N PO BOX 8800 CORCELETTE QUEBEC GOA IRO CANADA
2	DEUTSCH FRANZOSISCHES FORSCHUNGSINSTITUT ST LOUIS H ERNST H LERR CEDEX 5 RUE DU GENERAL CASSAGNOU F 68301 SAINT LOUIS FRANCE
1	DIEHL GMBH AND CO M SCHILDKNECHT FISCHBACHSTRASSE 16 D 90552 ROTBENBACH AD PEGNITZ GERMANY
1	DYNAMEC RSCH AB A PERSSON PARADESGRND7 SODERTALJE S151 36 SWEDEN

NO. OF COPIES	ORGANIZATION
2	ETBS DSTI P BARNIER M SALLES ROUTE DE GUERAY BOITE POSTALE 712 18015 BOURGES CEDEX FRANCE
1	FEDERAL MINISTRY OF DEFENCE DIR OF EQPT & TECH LAND RUV 2 D HAUG POSTFACH 1328 53003 BONN GERMANY
4	FRANHOFER INSTITUT FUR KURZZEITDYNAMIK ERNST MACH INSTITUT V HOHLER E STRASSBURGER R TRAM K THOMA ECKERSTRASSE4 D 79 104 FREIBURG GERMANY
1	MINISTRY OF DEFENCE DGA/SPART C CANNAVO 10 PLACE GEORGES CLEMENCEAU BP 19 F 92211 SAINT CLOUD CEDEX FRANCE
1	HIGH ENERGY DENSITY RSCH CTR V FORTOV G KANEL IZHORSKAY STR 13/19 MOSCOW 127412 RUSSIAN REPUBLIC
1	INGENIEURBURO DEISENROTH F DEISENROTH AUF DE HARDT 33 35 D 5204 LOHMAR 1 GERMANY
1	INST OF CHEMICAL PHYSICS S RAZORENOV 142432 CHERNOGOLOVKA MOSCOW REGION RUSSIAN REPUBLIC

NO. OF COPIES	ORGANIZATION
7	INST FOR PROBLEMS IN MATLS SCI S FIRSTOV B GALANOV O GRIGORIEV V KARTUZOV V KOVTUN Y MILMAN V TREFILOV 3 KRHYZHANOVSKY STR 252142 KIEV 142 UKRAINE
1	INST FOR PROBLEMS OFSTRENGTH G STEPANOV TIMIRY AZEVSKAYA STR 2 252014 KIEV UKRAINE
3	INST OF MECH ENGR PROBLEMS V BULATOV D INDEITSEV Y MESCHERYAKOV BOLSHOY 61 VO ST PETERSBURG 199178 RUSSIAN REPUBLIC
2	IOFFE PHYSICO TECH INST E DROBYSHEVSKI A KOZHUSHKO ST PETERSBURG 194021 RUSSIAN REPUBLIC
1	R OGORKIEWICZ 18 TEMPLE SHEEN LONDON SW 14 7RP UNITED KINGDOM
2	NATL DEFENCE HDQRTRS PMO MRCV MAJ PACEY PMO LAV A HODAK OTTOWA ONTARIO KIA OK2 CANADA
1	OTO BREDA M GUALCO VIA VALDIOCCHI 15 119136 LA SPEZIA ITALY
5	RAPHAEL BALLISTICS CTR M MAYSELESS Y PARTOM G ROSENBERG Z ROSENBERG Y YESHURUN BOX 2250 HAIFA 31021 ISRAEL

NO. OF COPIES	ORGANIZATION
1	ROYAL MILITARY ACADEMY E CELENS RENAISSANCE AVE 30 B 1040 BRUSSELS BELGIUM
1	ROYAL NETHERLANDS ARMY JHOENEVELD V D BURCHLAAN 31 PO BOX 90822 2509 LS THE HAGUE NETHERLANDS
1	DEFENCE MATERIEL ADMIN WEAPONS DIRECTORATE A BERG S 11588 STOCKHOLM SWEDEN
2	CENTRE DE RECHERCHES ET D`ETUDES D'ARCUEIL D BOUVART C COTTENNOT 16 BIS AVENUE PRIEUR DE LA COTE D'OR F 94114 ARCUEIL CEDEX FRANCE